Cardiopulmonary Resuscitation

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KEYWORDS

- Point-of-care ultrasonography • Cardiopulmonary resuscitation • Cardiac arrest
- Pulseless electrical activity • Transesophageal echocardiography
- Transthoracic echocardiography

KEY POINTS

- Point-of-care ultrasonography is a useful tool in cardiac arrest to identify reversible etiologies of arrest as well as the presence or absence of spontaneous cardiac motion.
- Absence of spontaneous cardiac motion is associated with low likelihood of return of spontaneous circulation.
- Transesophageal echocardiography may be a useful diagnostic aid when transthoracic imaging is insufficiency, and guide optimal quality of chest compressions.
- Many cardiac arrest ultrasound protocols have been described, and emphasize systematic, qualitative assessment for reversible etiologies of arrest while minimizing disruptions to chest compressions.

Video content accompanies this article at http://www.criticalcare.theclinics.com.

INTRODUCTION

Ultrasonography has become an invaluable tool in the management of cardiac arrest, offering real-time visualization and aiding in critical decision-making processes. Applications of point-of-care ultrasonography (POCUS) in cardiac arrest are multifaceted and employ a range of ultrasound imaging techniques. While transthoracic echocardiography (TTE) has been historically most popular due to its widespread availability, recently transesophageal echocardiography (TEE) has been increasingly utilized.

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Abbreviations	
ACLS	advanced cardiovascular life support
CASA	Cardiac Arrest Sonographic Assessment
CAUSE	Cardiac Arrest Ultrasound Exam
CPR	cardiopulmonary resuscitation
DVT	deep vein thrombosis
ECMO	extracorporeal membrane oxygenation
eCPR	extracorporeal CPR
FAST	focused assessment with sonography in trauma
FEER	Focused Echocardiographic Evaluation in Resuscitation
IHCA	in-hospital cardiac arrest
NFI	no-flow interval
POCUS	point-of-care ultrasonography
ROSC	return of spontaneous circulation
RV	right ventricular
TEE	transesophageal echocardiography
TTE	transthoracic echocardiography

The benefits of POCUS integration with cardiac arrest management include identifying a reversible cause of arrest, aiding in prognostication, improving the quality of cardiopulmonary resuscitation (CPR), assisting in rhythm identification/confirmation, as well as assisting in confirmation of return of spontaneous circulation (ROSC). Additional body ultrasound imaging, such as vascular (venous and arterial), thoracic, and abdominal examination, may also aid the clinician in their management of the patient.

ULTRASOUND FINDINGS OF REVERSIBLE ETIOLOGIES OF CARDIAC ARREST

Ultrasound offers several significant advantages over standard advanced cardiovascular life support (ACLS) protocols in identifying reversible causes of cardiac arrest. Traditional protocols are heavily reliant on clinical assessment and electrocardiographic findings that are limited due to the lack of direct visualization of underlying pathologies.

Pathologies that can be quickly identified and, therefore, rapidly intervened upon include cardiac tamponade, massive pulmonary embolism, tension pneumothorax, intra-abdominal hemorrhage, and aortic dissection. Diagnosis of these pathologies relies heavily on the use of echocardiography; however, echocardiography itself may be insufficient. POCUS examination may demonstrate additional findings that improve identification of arrest etiology.

Cardiac Tamponade

Cardiac tamponade is defined as an accumulation of fluid within the pericardial sac resulting in an increased external compressive pressure, which ultimately reduces right ventricular (RV) filling and decreased cardiac output. Cardiac tamponade has nonultrasonographic findings such as decreased electrocardiogram (ECG) amplitude and electrical alternans, elevated jugular venous distension, muffled heart sounds, and pulsus paradoxus; however, these all lack practical utility due to poor testing characteristics as well as limited evaluation intra-arrest.[1–3]

Echocardiographic findings of cardiac tamponade include the presence of a pericardial effusion, systolic right atrial collapse, diastolic RV collapse, transmitral and transtricuspid respiratory flow variation, and a dilated inferior vena cava. The most important ultrasonographic finding during cardiac arrest is the presence of a pericardial effusion as other echocardiographic findings cannot be assessed in the absence

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of spontaneous circulation. Pericardial effusions on ultrasound appear as anechoic or hypoechoic (depending on fluid composition) and are best appreciated in a parasternal long axis or subxiphoid view[1–3] (Video 1). Although rapid accumulating small effusions may produce tamponade physiology in certain populations (ie, cardiac surgical patients), generally only moderate-to-large effusions are capable of producing arrest. Individual patient factors and clinical history should be incorporated as patients may have chronic effusions unrelated to the etiology of their arrest. Additionally, ultrasound can also assist with real-time visualization of pericardial drainage via pericardiocentesis.[4]

Pulmonary Embolism

Massive pulmonary embolism is a possible reversible cause that has several ultrasonographic features that may aid in increasing or decreasing the probability as the etiology of the cardiac arrest.

It is possible (particularly if utilizing TEE) to visualize the main pulmonary artery at its bifurcation with visualization of clot in this location being diagnostic.[5] Generally, other ultrasonographic findings during cardiac arrest increase the posttest probability of pulmonary embolism as the etiology and must be taken into context of the patient's clinical history and overall presentation. One echocardiographic finding that significantly raises the probability of massive pulmonary embolism as the etiology of cardiac arrest is the visualization of a clot in transit. Typically seen in the right atrium or ventricle, this mobile clot appears as an echogenic mass moving with blood flow.[6]

RV dilation and right ventricle to left ventricle ratio greater than 1 can also be seen in patients with pulmonary embolism. However, RV dilation is a nonspecific finding in late-stage cardiac arrest due to poor transpulmonary flow and venous pooling, as well as prolonged hypoxemia and acidosis. RV dilation alone is generally not sufficient to conclude the presence of a pulmonary embolism and additional information should be considered.[7,8]

Other echocardiographic findings of pulmonary embolism such as McConnell's sign, RV strain, decreased tricuspid annular plane excursion, elevated right ventricular systolic pressures, and early systolic notching are generally not applicable in the setting of ongoing CPR although may become relevant if ROSC is achieved.[7,8]

Additional adjunct ultrasonographic findings that raise the probability of pulmonary embolism as the etiology of the arrest includes the presence of a deep vein thrombosis (DVT). This is seen as a hypoechoic intraluminal-filling defect and can quickly be identified at bedside. These intraluminal defects lack compressibility from external force (Video 2). Quickly identifying the large veins in the lower extremity (femoral and popliteal) for the presence of a DVT can raise the clinician's posttest probability of pulmonary embolism (PE) as the etiology of arrest. Taken together, the presence of a DVT along with an enlarged RV in the appropriate clinical history setting may reach a posttest probability threshold for intra-arrest thrombolytic therapy.[9,10]

Tension Pneumothorax

Tension pneumothorax is defined as a continuous buildup of air within the pleural space ultimately leading to significantly increased intrathoracic pressure resulting in decreased venous return and eventual hemodynamic collapse. Pneumothoraces can occur due to a variety of processes including respiratory diseases (eg, asthma and chronic obstructive pulmonary disease [COPD]), trauma, iatrogenic during procedures (eg, central line placement), as well as spontaneous. The rate of tension pneumothorax as an etiology of cardiac arrest is rare outside of inciting trauma, but the

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rapid identification is significant as it represents an easily reversible condition. Ultrasound is more sensitive than standard chest radiography for the detection of a pneumothorax and has the added advantage of speed, as obtaining a radiograph during a cardiac arrest is generally not feasible.[11] Similar to cardiac tamponade, tension pneumothorax has known physical examination findings such as absent breath sounds and distended neck veins; however, such findings are once again nearly impossible to evaluate for in real time intra-arrest.

Ultrasound findings in a pneumothorax include absence of lung sliding, identification of a "lung point," and absence of typical lung findings such as B-lines. The use of a high-frequency linear probe (5–13 MHz) is generally recommended for improved resolution of the pleural–pleural interface with the probe oriented cranial-caudal on the most anterior portion of the thorax between 2 rib spaces. In an unaffected lung, the visceral and parietal pleural slide against each other creating a characteristic motion denoted as lung sliding. In the presence of a pneumothorax, however, the separation of these layers by air results in the appearance of a static pleural line (Video 3). Ventilation is required to visualize lung sliding, and therefore, visualization of the pleural–pleural interface should be done during a period of ventilation. It should be noted that lack of lung sliding during ventilation may be due to other causes such unilateral bronchus intubation or complete bronchus obstruction by a foreign body. M-mode may also be utilized to confirm lack of sliding with the "barcode" sign typically used to describe the obtained image.[8,12]

A possible additional finding is the identification of a "lung point," which represents the junction of where normal lung sliding meets the pneumothorax (Video 4). This is a highly specific finding as it demonstrates both normal and abnormal lung in a single image and, therefore, does not have the same pitfall as lung sliding with regards to ventilation.[13]

It is additionally important to remember that an iatrogenic pneumothorax can occur due to closed chest compressions during a cardiac arrest. Identifying a pneumothorax after ROSC is vital given likely ongoing utilization of positive pressure ventilation and early identification and intervention may prevent future decompensation.

Aortic Dissection

Aortic dissection is a relatively rare etiology of cardiac arrest although the identification as the etiology of arrest may have drastic consequences for post-ROSC care. Aortic dissection can be identified as a hyperechoic line seen within the lumen of the aorta. This can be visualized on both transthoracic as well as TEE with the latter being superior in its ability to visualize a larger portion of the ascending and descending aorta (Video 3). It is important not to mistake a linear mirror artifact, which can sometimes occur as a true dissection flap, and multiview confirmation is recommended. Although not acutely reversible during the arrest, the identification of a dissection will likely impact postarrest care including faster consultation to the appropriate specialist as well as hemodynamic parameters.[14,15]

Hemorrhage

Although spontaneous nontraumatic etiologies of hemorrhagic shock leading to cardiac arrest occur, traumatic etiology is by far the most common. It is important to note that the mechanism of trauma also includes iatrogenic causes such as invasive procedures (thoracentesis or paracentesis), biopsies, as well as other surgical procedures. In patients fitting these criteria, assessment of possible hemorrhage as an etiology of arrest is imperative.

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Intra-abdominal

Several ultrasonographic protocols assessing for intra-abdominal free fluid have been developed with the focused assessment with sonography in trauma (FAST) being the most widespread and utilized. The assessment for intra-abdominal free fluid that is presumed to be blood in the presence of trauma uses 3 main intra-abdominal sonographic windows; the right upper quadrant, the left upper quadrant, and the pelvic. Ultrasonographically, blood (as well as all fluid) appears anechoic. Using a phased array or curvilinear probe, the right upper quadrant is first visualized with attention to Morrison's pouch (the hepatic–renal interface), the tip of the liver, as well as the subdiaphragmatic/suprahepatic space. The left upper quadrant view is assessed for evidence of free fluid both in the spleno-renal recess as well as in the subdiaphragmatic region. The pelvis is evaluated for fluid posterior to the bladder with transverse and sagittal views obtained.[16,17]

Intrathoracic

Evaluation for a hemothorax is performed in the same manner as when evaluating for a transudative pleural effusion. Blood will once again appear as anechoic within the thoracic cavity above the level of the diaphragm. Depending on the length of time of accumulation, a hematocrit sign may be visualized. Clinical and patient factors once again must be integrated with the sonographic findings as pleural effusions can be incidental and may not be contributing to the etiology of arrest.[16,17]

ULTRASOUND PROGNOSTICATION OF CARDIAC ARREST

Survival of in-hospital cardiac arrest (IHCA) is improving, but still poor, and may be as low as 10.5% for nonshockable rhythms.[18–20] Periarrest advances in IHCA management include CPR quality feedback and early identification of reversible etiologies for arrest, which may be further informed by POCUS. Identification of cardiac motion by ultrasound is widely used to gain prognostic information regarding resuscitative efforts; however, professional guidelines recommend a strict scope, supporting the use of ultrasound for the confirmation of spontaneous cardiac activity or cardiac standstill and identifying reversible etiologies of arrest.[21–23]

Identification of pulseless electrical activity (PEA) is difficult, as evidenced by inconsistent performance by health care providers to locate a pulse within 10 seconds.[24–26] POCUS offers a unique tool for identifying "true" PEA (absence of cardiac motion in the presence of organized electrical activity, Video 5) from "pseudo" PEA (presence of cardiac motion in the presence of organized electrical activity). This distinction has been shown to be important because "pseudo" PEA occurs more frequently and is associated with superior physiologic profiles, including higher central aortic pressures, PaO_2 and response to epinephrine.[27–29] It remains to be determined whether this distinction translates to associated favorable clinical outcomes and can provide prognostic value.

Systematic review suggests "pseudo" PEA may be associated with "positive" outcomes, defined as ROSC, survival to hospital admission, and 24 hour survival, although there are several limitations in interpreting this data, including reported heterogeneity in the definition of absent spontaneous cardiac motion as well as provider bias.[28,30] In one review, transthoracic and transesophageal echocardiography examinations were performed both in the emergency department and prehospital setting. Fourteen out of 15 included studies demonstrated a statistically significant positive correlation between spontaneous cardiac activity and "positive" outcomes. Of pooled patients, spontaneous cardiac motion was identified in 60% patients with

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positive outcomes, and 12.4% patients with negative outcomes. Similarly, patients presenting in PEA, asystole, and ventricular fibrillation (VF) were found to have spontaneous cardiac motion the majority of the time (58.8%, 66.7%, and 72.1%, respectively). Conversely, absence of spontaneous cardiac motion was present in patients who did not achieve ROSC 82% of the time, with a 94% mortality prior to hospital admission.[28] In a second review, findings were more limited—any cardiac activity on initial assessment, return of organized cardiac activity on subsequent assessment, and identification of treatable pathology was associated with high specificity for short-term outcomes, including ROSC and survival to hospital admission. Less certain prognostic factors, supported only be few observational studies, included the presence of organized cardiac rhythm, nonorganized or unspecified cardiac rhythm on any examination or every examination, return of organized rhythm on subsequent examination, and coalescent echo contrast.[30]

Interestingly, cardiac standstill identified at increasing time points during CPR was associated with increasing positive predictive value for mortality.[31,32] In one study, cardiac standstill predicted non-ROSC with 46.5% incidence on initial examination, 85.7% at 6 minutes of CPR, and 100% at 10 minutes of CPR.[31] Similarly, another study found cardiac standstill to carry 100% positive predictive value and negative predictive value at 10 minutes of CPR.[32]

Ultrasound identification of specific etiologies has been associated with ROSC and survival to hospital discharge.[30] For instance, identification of pericardial effusion leading to pericardiocentesis carried improved survival (15.4% vs 1.3%).[33] In another study, there were no instances of CPR cessation when the underlying etiology was identified as hypovolemia, RV enlargement, or pericardial tamponade.[34]

ULTRASOUND TO IMPROVE CARDIOPULMONARY RESUSCITATION QUALITY

Echocardiography in Cardiac Arrest Protocols

Point-of-care transthoracic echo during cardiac arrest has been associated with compression interruptions that are approximately double the 10 second maximum suggested by professional associations.[23,35–37] Compression pauses can be minimized using protocols that remind resuscitative teams to minimize pauses, or TEE.[37,38] One of the first POCUS protocols developed to guide resuscitation was the Focused Echocardiographic Evaluation in Resuscitation (FEER) protocol developed in 2017.[27] Since that time, several other protocols have been established, including the Cardiac Arrest Ultrasound Exam (CAUSE), Cardiac Arrest Sonographic Assessment (CASA), and the Echocardiographic Assessment using Subcostal-only view in Advanced Life Support.[38–40] While no single protocol has demonstrated superiority over the others, common features of all protocols include initial examination with a subcostal 4 chamber view, rapid assessment of reversible etiologies of arrest, and strict adherence to ACLS guidelines so that chest compressions are not interrupted for more than 10 seconds.

The FEER protocol outlines a suggested choreography for using ultrasound during ACLS.[27] It consists of 4 repeatable phases: (1) preparation of the ultrasound before pausing chest compressions, (2) image acquisition during the pause, (3) resumption of CPR, and (4) interpretation of ultrasound images during ongoing chest compressions. The preparation phase occurs during ongoing chest compressions; it includes readying and testing the ultrasound machine and positioning the transducer on the patient during the final seconds of the CPR cycle. Once chest compressions are paused, a subcostal 4 chamber image of the heart is usually acquired as rapidly as possible while a code timekeeper counts down the allotted 10 seconds to minimize the

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no-flow interval (NFI). The FEER protocol prioritizes minimizing the NFI by suggesting that compressions can be resumed if the heart cannot be identified on ultrasound after 3 seconds, and the code leader should always command that chest compressions resume after 9 seconds at the latest. After resuming CPR, the acquired images are interpreted and integrated into clinical management with the goal of identifying an etiology for the arrest. The ultrasound examination may be repeated throughout ACLS, during each pause in chest compressions, with the option to attempt different cardiac views if the subxiphoid view is difficult to obtain.

The CAUSE protocol does not outline the choreography of the ultrasound examination like the FEER protocol; instead, it emphasizes obtaining a 4 chamber view of the heart and including lung windows.[39] Then, it discusses the findings that would be present with cardiac tamponade, hypovolemia, massive pulmonary emboli, and tension pneumothorax.

The CASA protocol is a hybrid of the FEER and CAUSE protocols.[38] The CASA protocol re-emphasizes having someone count down 10 seconds during the rhythm checks, and suggests using the ultrasound examination to look for a single finding during each pause in compressions. The CASA protocol suggests looking for cardiac tamponade during the first rhythm check, right heart strain during the second pause, and cardiac activity during the third. Lung and FAST examinations are suggested if clinically indicated.

Optimization of Chest Compression Location

Published protocols have focused on minimizing the NFI by obtaining transthoracic images during the 10 second rhythm check. However, one case series suggests that transthoracic images may be obtained during ongoing chest compressions in select patients.[41] The authors of this series admit that obtaining adequate transthoracic images during ongoing chest compressions, "may be a challenge due to crowding of personnel and equipment, the patient's body habitus, comorbidities like COPD, environmental factors leading to skin and muscle noncompliance, and vigorous movement of the thorax impeding the ability to obtain views." In 4 of the 5 cases discussed in this series, the treating physicians noted that standard chest compressions were not adequately compressing the heart chambers, and directions were given to move the chest compressions to a more appropriate location. In the last case, cardiac tamponade was identified and treated.

The idea that standard chest compressions may be in the wrong location is not new. Due to anatomic variation, it is highly unlikely that one standardized location would work best for all patients; a more tailored approach is likely ideal.[42–45] A plethora of radiologic research using computed tomography and MRI has demonstrated that standard chest compressions are likely to be in the wrong place most of the time, potentially preventing forward blood flow.[46–51] In 2009, a case series of 34 cardiac arrest patients, evaluated with TEE imaging, demonstrated that none of them had chest compressions over the ventricles; 59% had compressions over the ascending thoracic aorta, and the remaining 41% over the left ventricular outflow tract.[52] More recent study with TEE has corroborated the fact that chest compressions are often not located over the ventricles.[53–56] If the cardiac pump model dominates at any point during cardiac arrest, evaluating the effectiveness of chest compressions may be one of the most important reasons to perform echocardiography during CPR. Animal studies have demonstrated that compression of the left ventricle maximizes hemodynamics and short-term survival, and human data have shown that there is an association between the area of maximal compression and ROSC.[54,57–60] One small study demonstrated that aortic valve opening is the only echo finding predictive of ROSC;

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aortic valve opening seems to be a good measure of quality chest compressions and is much simpler to identify than the area of maximal compression.[61]

Although there currently is not enough high-level evidence to definitively recommend that the location of chest compressions be maximized with echocardiography in every cardiac arrest case, there is enough building evidence that practitioners who want to avoid doing more harm than good with chest compressions will at least evaluate for aortic valve opening to ensure the compressions being performed are achieving the anticipated result. This may be attempted with either transthoracic or transesophageal echo, the latter being much simpler during ongoing chest compressions for operators familiar with basic TEE.

The Role of Transesophageal Echocardiography

For health care providers who are able to perform basic TEE during cardiac arrest, there are several substantial advantages over TTE imaging. TTE is noninvasive with little risk of harm; however, some potential disadvantages may render surface imaging less useful. Patient-related factors such as body habitus, obstructive lung disease, gastric insufflation, and defibrillation pad placement may make image acquisition challenging when utilizing TTE. In addition, transducer placement is often in close proximity to chest compressions, which often makes image acquisition challenging or threatens to compromise ongoing CPR. As discussed earlier, TTE has been associated with prolonged NFI unless a protocol is used to ensure rhythm checks are kept to less than 10 seconds, and there is a major advantage to observing the quality of ongoing chest compressions, which is often challenging or impossible with TTE. For all of these reasons, over the past decade, there has been an accelerated interest in using transesophageal TEE as an improved means to visualize cardiac structures and monitor resuscitative efforts during CPR.

The patient-related disadvantages of TTE are almost always overcome with TEE because the transducer rests directly behind the left atrium, making image acquisition much simpler once the probe is in place. The TEE operator stands at the head of the bed, allowing image acquisition without having to overcome the challenges of working close to the personnel performing chest compressions or other procedures. Rhythm checks are shorter using TEE when compared to TTE, even when protocols are not being used to reduce the NFI.[37] In addition, TEE imaging can be performed continuously throughout the entire resuscitation, including chest compressions and rhythm checks, which allows the operator to evaluate for the etiology of cardiac arrest as well as monitor the quality of chest compressions.[62]

Potential disadvantages of TEE include iatrogenic injury during transducer placement, the cost of TEE transducer purchase and maintenance, and the need for additional training. In addition, imaging of noncardiac structures, such as the lung, abdomen, or lower extremity vasculature may not be possible. Currently, the risk of iatrogenic injury due to TEE in cardiac arrest patients is still unknown and must be taken in the context that some injury is expected during CPR in an effort to save a life.[63–65] The largest series of TEE in cardiac arrest to date reported one complication during a series of 557 TEE examinations; an endotracheal tube that had previously been dislodged was identified and replaced without further complication.[66] In another series of 396 TEE examinations performed by emergency and intensivist physicians, 8 (2%) complications were reported.[67] Six were upper gastrointestinal bleeding within a week of the examination, and 2 were oropharyngeal bleeding. Only 3 (0.7%) of the complications were thought to be possibly related to the TEE examination, and no esophageal/gastric perforations were reported. No mortality was related to the reported bleeding complications. The same authors published another study demonstrating

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that patients with coagulopathy or thrombocytopenia are not at any higher risk of bleeding complications from TEE.[68]

In regard to additional training needed to perform TEE, anyone performing TEE during cardiac arrest should go through the TEE training requirements endorsed by their respective professional society. In most instances, only basic TEE skills are necessary to evaluate for the etiology of arrest and quality of chest compressions, and simplified protocols have been suggested for the intra-arrest TEE evaluation.[62,69,70] More complicated examinations may be considered in the postresuscitation period.

Ultrasound Guidance for Extracorporeal Cardiopulmonary Resuscitation

Extracorporeal CPR (eCPR) may improve blood flow in refractory cardiac arrest and has been associated with improved short-term and long-term survival, as well as favorable neurologic outcomes.[71] POCUS may be an invaluable tool in eCPR to both guide vascular cannulation and evaluate the quality of extracorporeal support. A detailed discussion regarding ultrasound guidance placement and evaluation of mechanical circulatory support is discussed elsewhere.

There is no single imaging modality shown to be superior in guiding extracorporeal cannula placement; however, periarrest ultrasound guidance carries several clinical advantages, including the avoidance of transport to a fluoroscopy suite or operating room. The Extracorporeal Life Support Organization recommends ultrasound imaging for both visualization of guidewire and final cannula placement.[72] Ultrasound guidance of vascular access increases first pass success rate and time to successful placement, while minimizing major vascular injury.[73–76] One review demonstrated a 15% incidence of major vascular injury (hemorrhage, arteriovenous fistula, and thromboses) following extracorporeal membrane oxygenation (ECMO) cannulation.[77] Another review found that limb ischemia secondary to femoral arterial injury occurred at a rate of 16.9% following peripheral veno-arterial ECMO cannulation, and required fasciotomy in 10.3% patients.[78] In addition to guiding cannula placement in real-time, ultrasound may be used to identify factors associated with successful cannulation, including femoral artery diameter of 4.5 mm or greater and LVEF of greater than 20%, and to guide cannula sizing.[79,80]

Periarrest evaluation of cardiac structures is paramount to successful eCPR. Early identification of intracardiac shunts, significant aortic insufficiency, or aortic injury may identify patients with contraindication of ECMO. In addition, successful eCPR should demonstrate LV "unloading," defined by left atrial and left ventricular decompression, aortic valve opening, and the absence of signs of blood stasis, including spontaneous contrast or thrombus.[81] If LV unloading is insufficient, interventions such as an intra-aortic balloon pump, interatrial septostomy, or miniature left ventricular assist device (Impella, Abiomed, Danvers, MA) should be considered. The combination of ECMO and Impella has been shown to perform superiorly to ECMO alone.[82]

DISCUSSION

POCUS application during cardiac arrest is likely to increase due to growing provider familiarity and accessibility to TTE, TEE, and body ultrasonography. There are many described cardiac arrest ultrasound protocols, yet many share the common theme to provide real-time, qualitative information regarding cardiac, vascular, lung, and body structures to identify the presence or absence of spontaneous cardiac activity and rule out certain reversible etiologies of arrest without compromising the quality of CPR, specifically, chest compression fraction. For certain pathologies, rapid identification may directly lead to improved survival due to early definitive management.

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However, general translation of POCUS application with improved arrest survivability or hospital outcomes is challenging due to the heterogeneous nature of POCUS application, including protocol used, sonographer level of experience, and definition of clinical findings. Additionally, there is growing support for POCUS application to guide CPR quality via optimization of chest compression location, confirmation or identification of rhythm change, identification of mechanical pulse, and guidance and assessment of mechanical circulatory support, that is, eCPR. Despite increasing awareness for the value of POCUS in cardiac arrest applications, there is a need for larger, randomized trials investigating POCUS application or accessibility and the effect of provider training, as well as standardization of reporting of clinical findings.

CLINICS CARE POINTS

- Ultrasound may readily diagnose reversible etiologies of cardiac arrest
- Visualization of "clot in transit" may diagnose acute pulmonary embolism.
- Pulmonary embolism cannot be diagnosed solely from visualization of acute RV dilation. However, acute RV dilation in the presence of DVT may increase the likelihood for pulmonary embolism.
- Absence of lung sliding itself does not diagnose acute tension pneumothorax. Visualization of lung point carries high sensitivity and specificity for tension pneumothorax.
- Ultrasound in cardiac arrest has been associated with prolonged NFIs. These can be minimized by utilizing established cardiac arrest ultrasound protocols.
- "Pseudo"-PEA is defined by organized electrical activity with ultrasound visualization of cardiac motion. "Pseudo"-PEA is associated with positive arrest outcomes.
- "True"-PEA is defined by organized electrical activity with ultrasound visualization of cardiac standstill. "True"-PEA is associated with negative arrest outcomes.
- Ultrasound may assist in the guidance of optimal compression location.
- TEE imaging may be useful to diagnose etiologies of arrest during chest compressions and guide optimal compression location.
- Ultrasound may be utilized during eCPR to guide vascular access, minimize vascular complications, and provide real-time assessment of LV emptying.

DISCLOSURE

The authors have nothing to disclose.

SUPPLEMENTARY DATA

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